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This instrumentation project was to develop new techniques in experimental structural dynamics for use with a Scanning Laser Doppler Vibrometer purchased with a grant from the AFOSR. A Laser Vibrometry Laboratory was established and the equipment has been used for structural health monitoring and modal analysis research, and teaching experiments. The research results obtained are helping to improve damage detection techniques for large structures, and the upper frequency range of modal analysis testing has been extended from previous limits of 20KHz to 200KHz for small structures. The laser equipment is bringing new research and attracting more students to A&T University, and is drawing attention from the community. An American Society of Mechanical Engineers tour showed the Laser Vibrometry Laboratory to engineers from local industry, and a number of outside faculty have also visited the laboratory. The local television station Fox 8 did a short story on research activities at A&T and included a three second part on use of the laser. An article on the laser award was also published in the Greensboro News and Record newspaper. The AFOSR grant to purchase the laser system has been a tremendous benefit to A&T university, the students, faculty, and the community.

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FINAL TECHNICAL REPORT FOR THE FY97 DURIP GRANT No. F49620-97-1-0165

NEW TECHNIQUES IN EXPERIMENTAL STRUCTURAL DYNAMICS USING A SCANNING LASER VIBROMETER

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NEW TECHNIQUES IN EXPERIMENTAL STRUCTURAL DYNAMICS USING A SCANNING LASER VIBROMETER

SUMMARY

The objective of this research was to develop new techniques in experimental structural dynamics for use with a Scanning Laser Doppler Vibrometer (SLDV) that was purchased with an equipment grant from the AFOSR. Ordering and getting the equipment operational took over half the period of the one year grant, and the equipment has had about six months use at the time of writing this report. The exact equipment requested in the revised proposal was purchased. The equipment consists of the PSV-200-1 scanning vibrometer and options. A Laser Vibrometry Laboratory was established for use of the new equipment.

Thus far, the equipment has been used for structural health monitoring and modal analysis research, an undergraduate teaching experiment, and a graduate course project. The undergraduate mechanical engineering course used the laser for an experiment showing experimental modal analysis, which was tied to the classroom theory. Error sources when using the SLDV were investigated by two project groups in the Instrumentation course for mechanical engineering graduate students. Similar use of the laser is planned for following semesters.

The laser equipment enabled the PI of this project to get two new small grants from United Technologies Research Center and Sandia National Laboratories both involving use of the laser. The SLDV is also being used on existing grants with Raytheon Systems, and NASA Marshall Space Flight Center. The different research uses of the laser are discussed in this report. Future experiments planned are also discussed.

The laser system is also helping to attract more students to come to A&T and perform research in the Structural Dynamics Laboratory. Prospective students have toured the Laser Vibrometry Laboratory at A&T and are impressed with the research equipment availalble. An American Society of Mechanical Engineers tour was also given of the Laser Vibrometry Laboratory, and about 20 engineers from local industry saw a demonstration on use of the laser. A number of faculty visitors have also seen the laser laboratory. The local television station Fox 8 did a short story on research activities at A&T and included a three second part on use of the laser. An article on the laser award was also published in the Greensboro News and Record newspaper.

Within the short period that it has been operational, the laser has been used almost daily for research and some teaching, and has attracted attention from the community. The research results obtained are helping to improve damage detection techniques for composite and metallic materials, and the upper frequecy range of modal analysis testing has been extended from previous limits of about 20KHz to 200KHz for small structures. The AFOSR grant to purchase the laser system is a tremendous benefit to A&T university, the students, faculty, and the community.

PROJECT RESULTS

1. EDUCATIONAL USE OF THE LASER SYSTEM

The laser was used for a demonstration experiment in the MEEN 581 Mechanical Vibration course for undergraduates. Experimental modal analysis was performed on a turbine blade from a jet engine. The concept of mode shapes taught in the classroom was demonstrated by animating the mode shapes of the blade using the laser system software.

In the MEEN 789 Instrumentation course for graduate students, two project groups investigated error sources in using the laser system. Besides looking at signal processing aspects such as filtering and windowing, an interesting result was that the motion of the test article due to ambient vibration in the building was the greatest error source. The laser can measure very low vibration levels and detects vibration from people walking down the stairs or in the hallway outside the lab.

In the faculty student opinion forms for the MEEN 581 course, the students usually give the laboratory experiments a high rating, and often comment that longer and more experiments should be performed. The laser experiment for the spring 98 semester was very well received by the students with similar comments.

Six undergraduate and six graduate students performed reserach in the structural Dynamics and Control Laboratory at A&T for the spring 98 semester. Most of these students will use the laser system before they leave A&T.

2. RESEARCH USE OF THE LASER SYSTEM

The different uses of the laser system are described below. These projects are in the beginning stage regarding use of the laser. In the spring 98 semester, one faculty member, one adjunct faculty member, and two graduate students used the laser system for research.

2.1 Health Monitoring of Composite Material Structures

Previoulsy accelerometers were used to detect damage in a curved fiberglass panel 48 in sq by ¼ in. Damage was detected by comparing before and after damage vibration response data. In the laser experiment, two piezoceramic patches (PZT) are used to excite the curved panel with a periodic chirp 1-500hz, and the SLDV was scanned over the panel to measure Frequency Response Funcitons (FRFs) at closely spaced points to detect damage. The symmetry of the panel and PZT patches was used to detect damage by comparing FRFs of symmetricallly located points on the panel. Damage was introduced by putting a two inch saw cut down from the top edge of the panel. The laser was scanned over the damage area and reflective tape is used at some points to minimize laser signal drop-out. The panel is shown in Figure 1. The measured FRFs are shown in Figures 2 and 3. Results show that adjacent FRFs near the cut have different amplitudes at certain frequencies. Adjacent FRFs away from damage have more similar amplitudes. Thus differences in paired FRFs at symmetrically located points can identify moderate to large damage to structures.

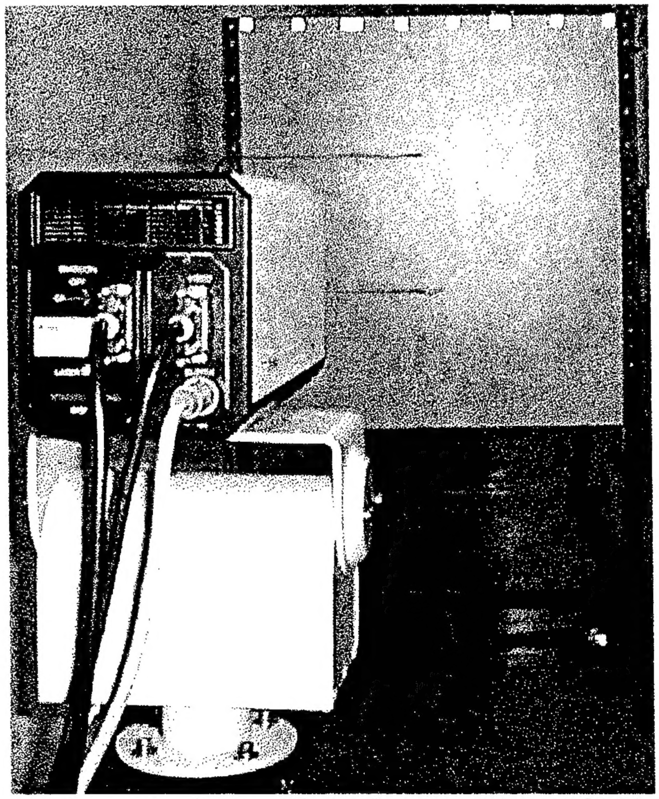

Figure 1. Curved fiberglass panel and SLDV

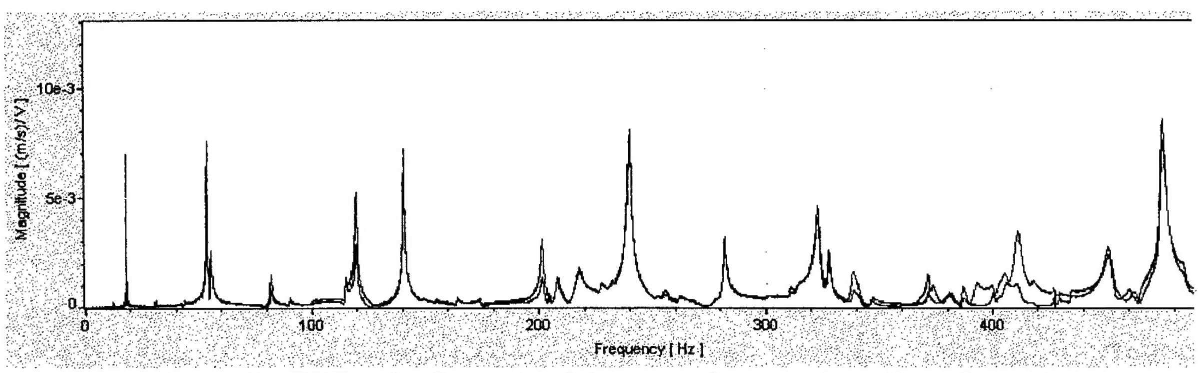

Figure 2. FRFs at adjacent points on undamaged section of panel

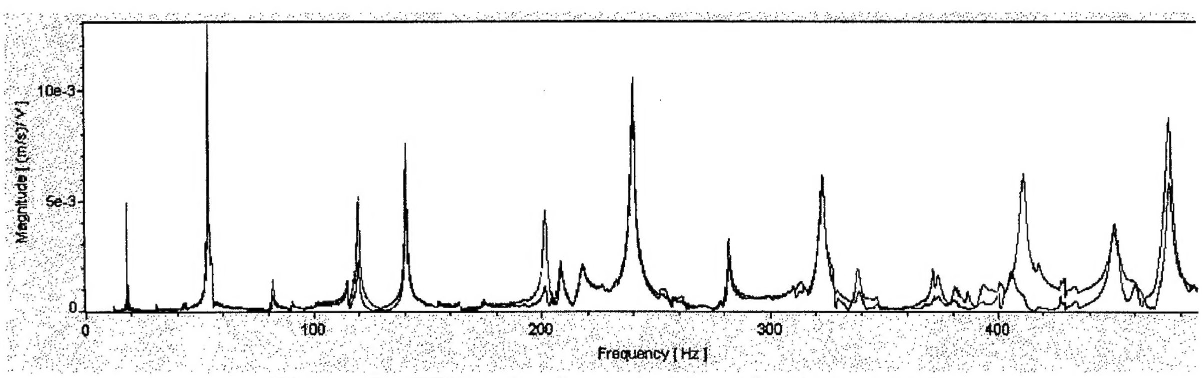

Figure 3. FRFs at adjacent sides of cut on panel

2.2 Modal Analysis of a Piezoceramic Mirror Scanner

An oscillating mirror scanner using a piezoceramic bimorph actuator shown in Figure 4 was designed by and A&T student to scan a laser beam over the surface of a structure. In the design it was important to have the lowest vibration mode above 30Hz. Since the scanner is quite small, measurement with an accelerometer would add mass and not be accurate. The SLDV was used to measure the lower mode shapes using a periodic chirp excitation, and in Figure 5 the 30Hz mode is shown which is almost a pure rotation as desired.

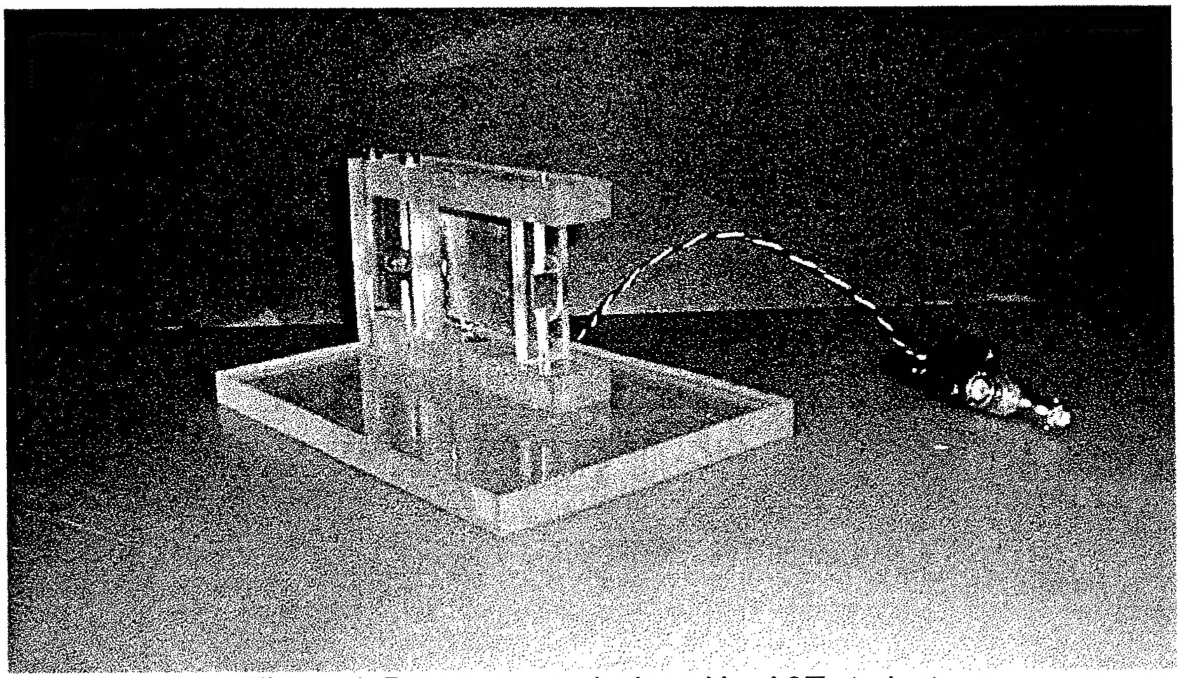

Figure 4. Beam sanner designed by A&T student

Figure 5. Rotational vibration mode at 31Hz of scanner measured by SLDV

2.3 Vibration Testing on a Panel

Vibration testing on a panel using the SLDV is shown in Figure 6. The FRFs for two different structural conditions are shown in Figures 7 and 8. The SLDV can detect relatively larger differences, but the very high modal density due to the complex geometry of the ribs and stiffeners of the panel makes high-frequency modes difficult to identify. However, overall changes in the magnitude of the FRFs did indicate two different structural designs. Research is continuing to improve the sensitivity of the technique by trying to go to higher frequency ranges. A lower frequency operational defleciton shape of the panel is shown in Figure 9.

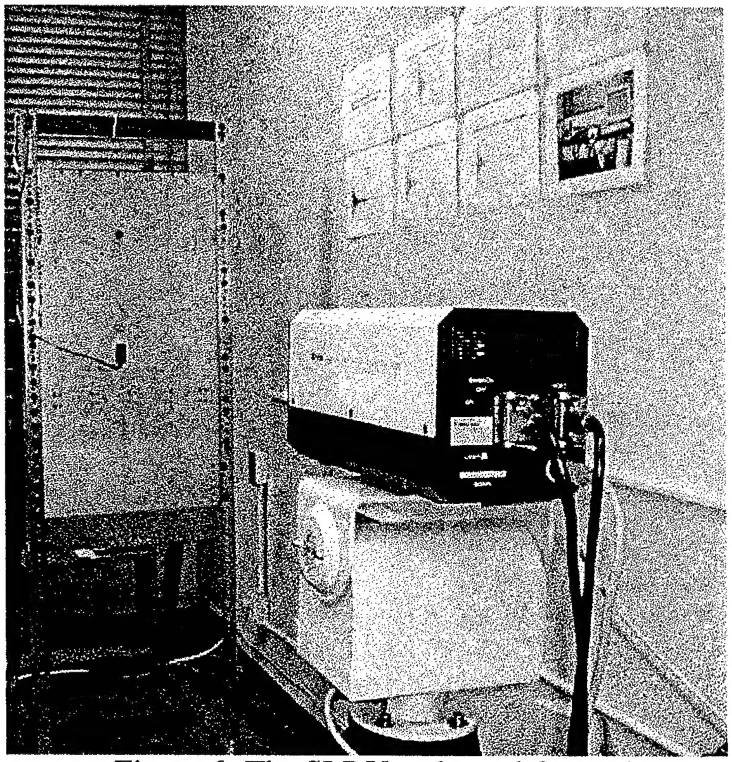

Figure 6. The SLDV and panel for testing

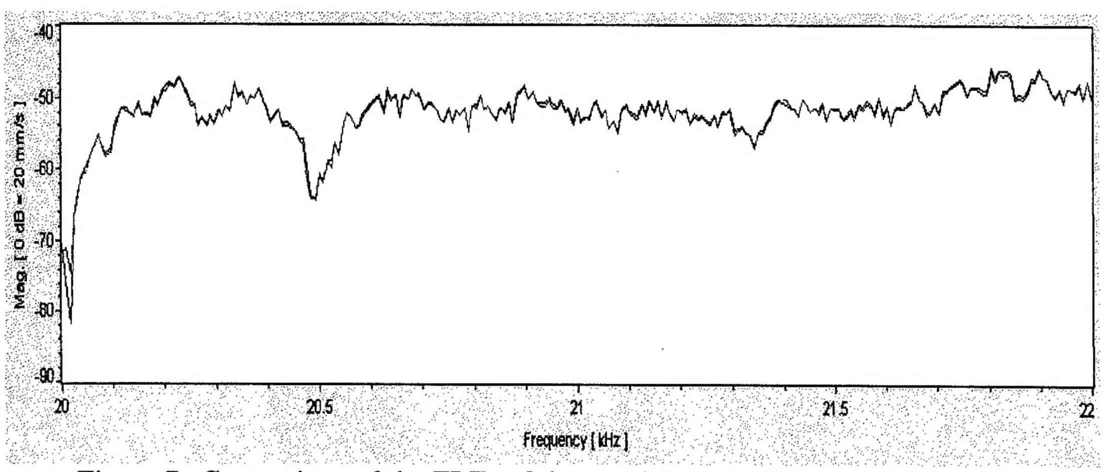

Figure 7. Comparison of the FRFs of the panel for two different measurements

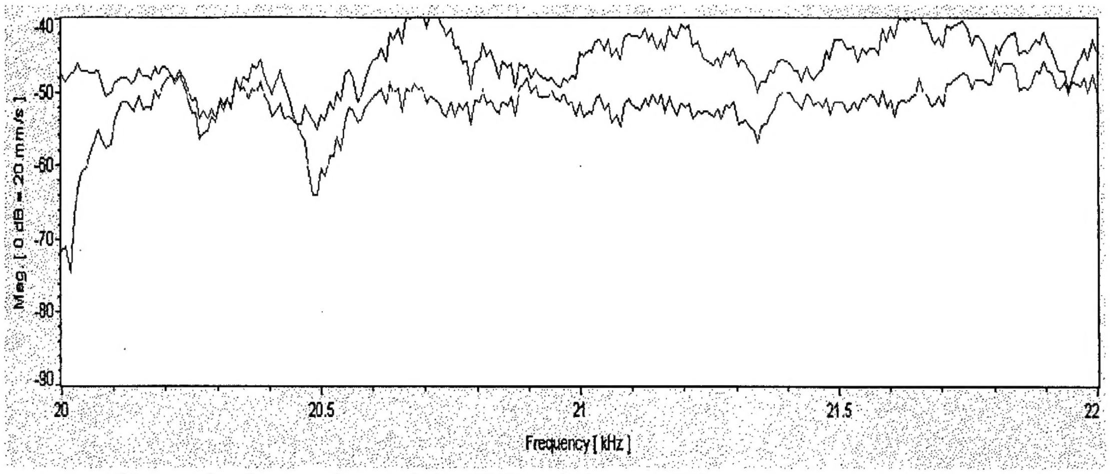

Figure 8. Comparison of the FRFs of the panel for two structural designs

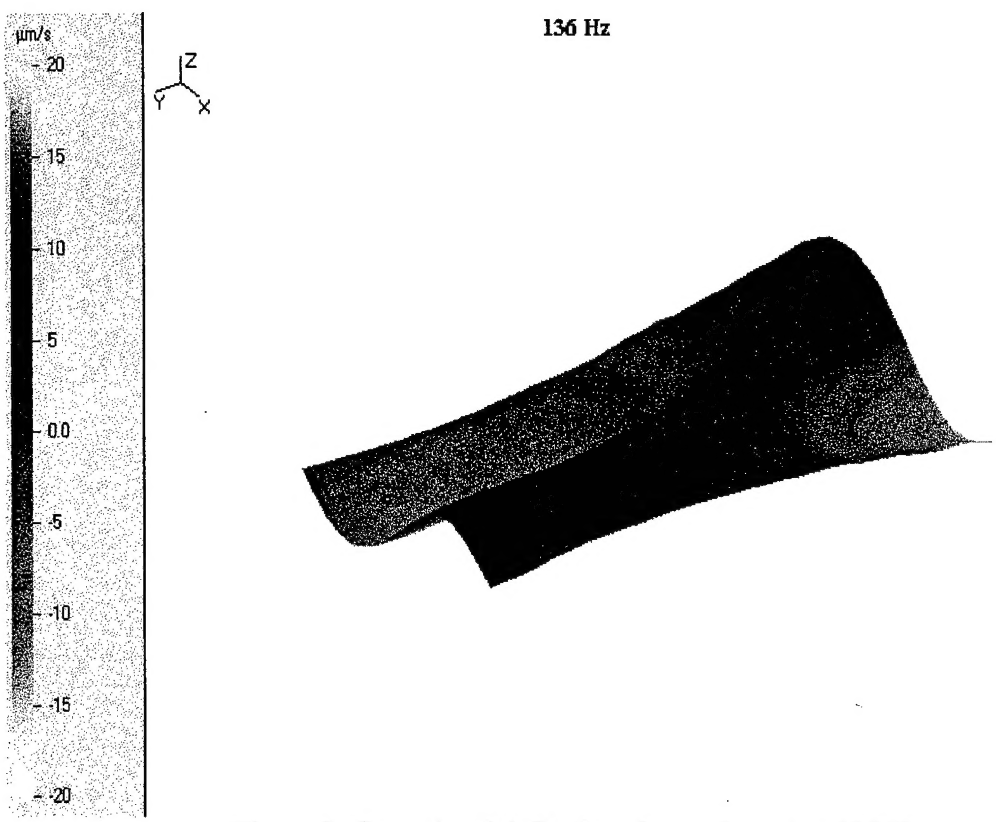

Figure 9. Operational deflection shape of panel at 136 Hz

2.4 Vibration Testing of a Model Wing

Testing of a model wing using the SLDV is show in Figure 10. The vibration mode shapes of the wind are computed to understand the bending and bending-torsion behavior. The mode shapes computed using the SLDV are shown in Figure 11. Note the bending-torsion coupling of the third mode. The PZT patches will be used to control the vibration of the wing in a wind tunnel.

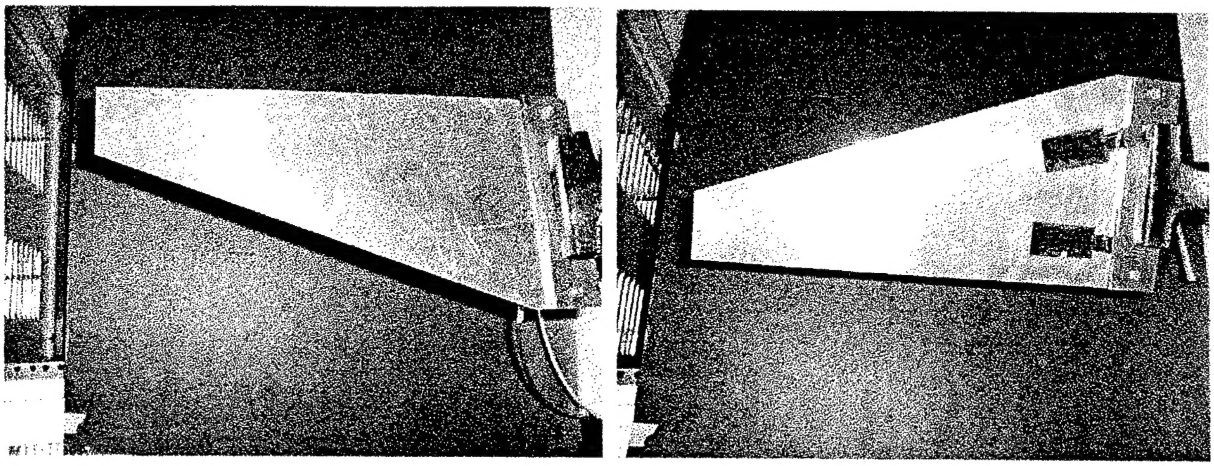

Figure 10. Model wing with piezoceramic actuators

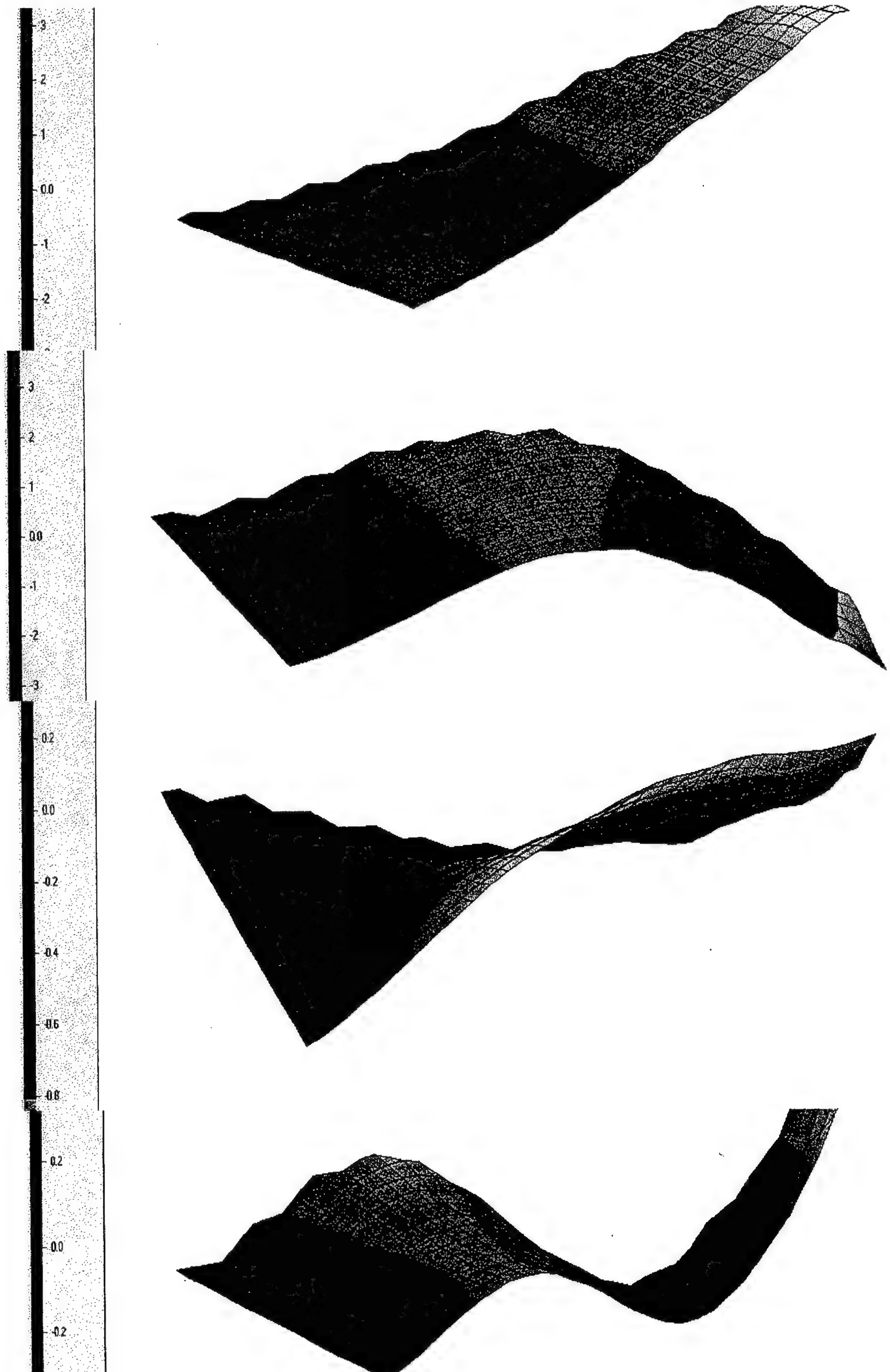

Figure 11. Vibration mode shapes of the wing model (18, 90, 120, 225 Hz)

Research has also been performed with the SLDV on another project, but could not be reported at this time.

2.5 Publications

Publications related to this grant are listed below. Since the laser has been operational for only a short time, there are the only publications, and they are in review.

1. Li, J., Schulz, M.J., Naser, A.H., Pai, P.F., and Chung, J.H., "Damage Detection on an Aircraft Wing Panel using Vibration Measurements," submitted to the ICAST'98 conferenece, 14-16 October, 1998, Cambridge, MA, abstract in review.

2. Schulz, M.J., Wheater, E.A., Pai, P.F., "Structural Damage Detection Using a Laser Vibrometer and Piezoceramic Patches," submitted to the IMAC-XXVII conference in Orlando, Fla., February 8-11, 1999, abstract in review.

3. Cooperative Research

The resarch performed in the Structural Dynamics Laboratory at A&T aims to leverage support from government, industry, and national laboratories to developo new techniques in health monitoring and vibration suppresion of structures. The equipment from this grant and other grants was used to establish a laser vibrometry laboratory at A&T. This laboratory contains about $450,000 of equipment, and is attracting new grants to A&T to perform research using this unique equipment. The laser system is too expensive for many organizations to purchase as a research tool. Since receiving the grant from the AFOSR, the United Technologies Research Center and Sandia National Laboratories have given A&T small research grants to perform laser testing. The laser system is or will be used on current grants from Raytheon Systems, NASA Marshall Space Flight Center, and the National Renewable Energy Laboratory. Thus the equipment grant from the AFOSR is helping to support projects from government and industry.

4. Budget

The cost for the requested equipment based on vendor quotes is given in Table 1. The total cost is $203,867.10 including tax, the cost share amount from NCA&TSU is $8,3669.10, and the DoD cost is $195,498. This is based on the revised lower budget submitted. All equipment listed in the budget was purchased for the prices listed.

Table 1. Cost of Scanning Laser Doppler Vibrometer System and Accessories

ITEM	COST
1. PSV200-1 Scanning Laser Vibrometer	$ 146,500
2. Total Options for all applications/portability	$ 49,420
a) PSV-Z-055-D Scan Head	$ 560
b) PSV-Z-061 Universal File Format	$ 5,950
c) PSV-Z-063 Storage of Time Data	$ 7,950
d) PSV-Z-7260 Lock-In Amplifier	$ 8,500
e) PSV-Z-068 High-Resolution FFT	$ 3,950
f) PSV-FFFT Integrated Waveform Gen.	$ 2,950
g) PSV-107 Tripod with Motor	$ 3,950
h) OMA-004 Carrying Cases	$ 3,450
i) OFV-055-C Close-up Scan Attachment	$ 3,800
j) PSV-Z-30 Ultrasonic Decoder	$ 8,360
3. Extended warranty 1-year	$ 7,837
TOTAL COST	$ 203,867
NCA&T COST SHARE	$ 8,369
DOD COST	$ 195,498

5.0 Conclusions and Future Work

The AFOSR grant for the laser system has increased research funding at A&T, increased student participation in research, promoted research collaboration with industry and a national laboratory, and increased recognition for university research within the community. The grant from the AFOSR is sincerely appreciated by the faculty and students at A&T university.

Future work planned using the SLDV includes: development of algorithms for damage detection using laser data, detecting damage using the ultrasonic decoder for the laser, estimating aerodynamic loads on flight vehicles by using the laser through a glass wall in a wind tunnel, using higher-order transmittance functions for damage detection, validation of linear and nonlinear and finite-element models, testing a section of a blade from a horizontal axis wind turbine, and active control of light-weight structures by scanning the laser over the structure.